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SPRAY DISTRIBUTION PATTERNS FROM A PIPER PA-18A AIRPLANE FLYING AT 50 FEET

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SPRAY DISTRIBUTION PATTERNS FROM A PIPER PA-18A AIRPLANE FLYING AT 50 FEET[1]

By D. A. Isler and J. S. Yuill[2]

The pattern of aerial spray deposited on the ground or on foliage is influenced by the arrangement of the nozzles along the boom attached to aircraft. Spray-distribution patterns from a Stearman airplane, flying at 50 feet, with various nozzle arrangements have been reported by Isler and Yuill.[3] This report describes similar studies made with a smaller plane, the Piper PA-18A. This plane has been used for control of forest insects in forest plantations, woodlots, and other small areas as well as around lakes and watercourses.

Effects of the following three nozzle arrangements on spray distribution across the swath are reported:

1. Standard, or even, spacing along the boom.
2. Inboard arrangement.
3. Outboard arrangement.

EQUIPMENT AND PROCEDURE

The Piper PA-18A airplane had a 135-h.p. engine and was equipped with dual spray apparatus (fig. 1) similar to that described by Miller and Isler.[4] Essentially this apparatus consists of two complete and independent spray systems that permit simultaneous applications from two different nozzle arrangements as a paired test.

The idea of using a dual sprayer for comparing the effect of nozzle location on spray distribution is based on the assumption that, when the two systems simultaneously deliver the same amount and kind of insecticide and when the same nozzle equipment and operational conditions are used, the resulting spray deposits should be identical.

Two spray tanks were mounted side by side behind the pilot in the space normally occupied by the standard Piper factory spray tank (fig. 2). One of the two spray pumps was located between and in front of the landing gear struts; the standard Piper pump mounting bracket was used. The other one was mounted at the lower left longeron just behind the point of attachment of the wing struts (fig. 3). Both were 1 1/4- x 1-inch centrifugal wind-driven pumps.

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[1] Based on work carried out jointly by Agricultural Engineering Research Division, Agricultural Research Service, and Division of Forest Insect Research, Forest Service, U.S. Department of Agriculture at the Agricultural Research Center, Beltsville, Md.

[2] Agricultural Engineer, Agricultural Engineering Research Division, Agricultural Research Service, and Entomologist, Division of Forest Insect Research, Forest Service, respectively. The authors gratefully acknowledge the assistance of the late J. M. Davis, S. W. Joyce, Jr., Bohdan Maksymiuk, J. P. Secrest, and H. W. White in conducting the flight tests and dye-tracer determinations.

[3] Isler, D. A., and Yuill, J. S. Spray distribution patterns from a Stearman airplane flying at 50 feet. U.S. Agr. Res. Serv., ARS 42-82. 1963.

[4] Miller, J. M., and Isler, D. A. Dual spray equipment for airplane spraying tests, U.S. Dept. Agr., Bur. Ent. and Plant Quar. ET-294. 1951.

Figure 1.--PA-18A airplane equipped with dual spray apparatus.

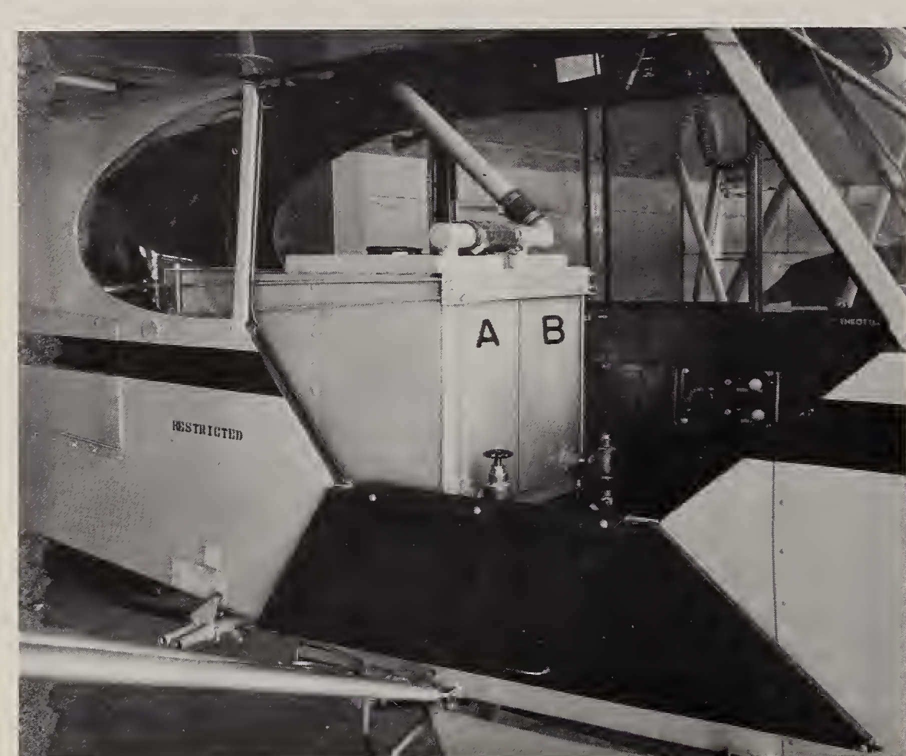

Figure 2.--Dual spray tanks mounted in PA-18A: A, right tank; B, left tank.

Two booms were located one behind the other; the standard Piper boom struts were used (fig. 4). These booms had been made about 1 foot longer than the wing span of the airplane for experimental purposes. For these tests, however, the maximum nozzle span used was only 29 feet 8 inches; or about 5 feet 8 inches shorter than the wing span, essentially the same as the commercial Piper spray boom.

Twenty-four Spraying Systems Company diaphragm check valves with T-8010 flat spray nozzles were used on each boom. Nozzle orifices were directed forward and upward 20 degrees to the thrust line of the plane on the front boom and forward and downward 20 degrees on the rear boom (fig. 4). With this orientation these nozzles produced an atomized spray having a mass median diameter of approximately 150 microns at 80 m.p.h. air speed and 25 p.s.i. spray pressure. This was within the range of atomization recommended for most forest spraying.

Figure 3.--Two spray pumps on PA-18A.

Figure 4.--Standard nozzle arrangement on front boom and outboard arrangement on rear boom. Pipe plugs in unused boom outlets at extreme outboard ends of booms and inboard end of rear boom.

The spray material used in both systems was a standard formula of 25 pounds of DDT dissolved in 19 gallons of Sovacide 544B (Socony - Vacuum Oil Co., Inc.) and diluted to 50 gallons with No. 2 fuel oil. Separate measurements were made of the aerial spray deposits from the two spray systems by the dye-tracer method.[5] A blue dye (National Brilliant Oil Blue[6]) was used at the rate of 2 pounds per 100 gallons of spray in one system, and an orange dye (Calco Oil

[5] Isler, D. A. Methods for evaluating coverage and drop size in forest spraying. Amer. Soc. Agr. Engin. Trans. 6(3): 231-233. 1963.

[6] Manufactured by Allied Chemical and Dye Corporation.

Orange[7]) at the rate of 5 pounds per 100 gallons of spray was used in the other. In conducting the test the dyes were alternated from one system to the other in order to average out possible errors due to differences in dyes, such as fading or spectrophotometer sensitivity.

Attempts were made to maintain the flow rate of each of the two spray systems as near as possible to 21.3 g.p.m. (gallons per minute). This is the flow rate required for an application of 1 g.p.a. (gallon per acre) on a swath two chains wide (132 feet) at a speed of 80 m.p.h.

All flights were made over a special test area on open ground (fig. 5). Four sampling lines, each 600 feet long and oriented to the cardinal compass directions, were placed on the area. The center of each line was a common point. Stakes 3 feet high were set at 5-foot intervals along each line for sampling points. A spring clip was attached to the top of each stake to hold two 6- x 6-inch flat aluminum plates (each with several hammer dents to keep them from sticking when stacked) for collecting the falling spray and one 3- x 5-inch white file card as a visual indicator of the distribution across the line (fig. 6).

All test flights were made early in the morning or during late evening, when air movement was least. Most of them were made when wind velocities were less than 5 m.p.h. and when a stable or inversion gradient of temperature existed between heights of 5 and 50 feet above ground; all of them were made as nearly as possible into the wind. To apply the spray, the pilot flew a straight and level course across the test area. Both sprayer systems were turned on when the plane approached to within 500 feet of the test area and they were left on until it reached a point at least 1,000 feet beyond the area. The plane was flown 50 feet above the ground at an indicated air speed of 80 m.p.h.

Figure 5.--Test area at Beltsville airport. Four 600-foot sampling lines.

[7] Manufactured by American Cyanimid Company.

Figure 6.--Two aluminum plates and one paper card for sampling spray deposits.

Yellow weather balloons inflated to a diameter of about 24 inches and tied to 50 feet of fishline were used as markers to guide the pilot. One was placed at the center point of the sampling lines and another directly upwind about 300 feet from the center point of the test area. Smoke flares and the lean of the balloon strings were used to determine the wind direction. As the wind shifted, the position of the upwind balloon was changed. In making the spray run, the pilot flew over the two balloons.

After each flight the spray was allowed to settle for 10 minutes before samples of it were collected. The line selected for sampling was the one most nearly perpendicular to the line of flight. The aluminum plates bearing spray deposits were collected from the part of this line receiving spray, as revealed by the presence of dye markings on the white cards. Before the plates were transported, the upper surfaces of each pair were turned together and the two were then stacked in a special carrying box. In the laboratory, the deposits on the two plates from each location on the line were washed off with an acetone spray and combined to form a single sample. The amount of dye in each sample was then measured in a spectrophotometer. This was done by making separate readings at two different specific wavelengths--one for each dye.

The spectrophotometer measurements were then converted into terms of gallons of spray per acre and the data plotted as a deposit curve. When the flight line deviated more than 15° from the normal (right angle to sampling line), the 5-foot interval between sampling points was corrected to the true right-angle distance by the formula:

$$i = 5 (\cos \phi)$$

Where i = corrected interval distance

ϕ = angle of deviation of flight line from normal (right angle to sampling line)

Comparisons of the spray deposit from the various boom and nozzle arrangement tests were made on the basis of uniformity of distribution across the swath, the width of swath at various deposit levels, and the percentage of the spray released from the plane that was recovered on the ground. The swath width at various deposit levels was measured from the deposit graphs. Since a deposit level of 0.5 g.p.a. is generally above the minimum required for control of most forest insect defoliators, the differences in swath widths at rates above 0.5 were not considered in this analysis. The percentage of spray recovered was calculated by the formula: (quantity of spray deposited divided by quantity of spray released) X 100 = percentage recovery.

RESULTS

Spray Deposits From Front and Rear Booms

Spray deposits from the front and rear booms were compared to determine whether spray from the two booms with a similar nozzle arrangement produced similar distribution patterns. The arrangement of nozzles on the front boom is shown in figure 7. An identical arrangement was used on the rear boom except that they were located below the boom. The first three inboard connections on the left half of each boom were not used during any of the tests because of the spray pump mounted on that side.

There were four test flights in this series. The flow rate from the front boom was 20.4 g.p.m. and from the rear boom 21.3 g.p.m. Observations of the wind speed and air temperature were made at heights of 5 and 50 feet above ground during the tests (table 1). The wind speed was 6 m.p.h. or less, and there was an inversion of 1.8 to 4.2 degrees for all tests.

Spray recovery for the four flights averaged 73.7 percent from the front boom and 72.7 from the rear boom (table 1).

A graphic comparison of spray deposit from the two booms with the same nozzle arrangement is shown in figure 8. The curves show the average for the three flights (1, 2, and 4) of the series that were most directly upwind. The zero distance, or middle of the curves, represents the point of minimum deposit and appears as a trough between the two peaks. This point was selected rather than the flight line in order to minimize the effect of crossdrift, which otherwise would have tended to obscure the peaks and trough when several flights were averaged. Spray distribution from the two booms was almost identical, with no practical difference in the peaks of deposit from them.

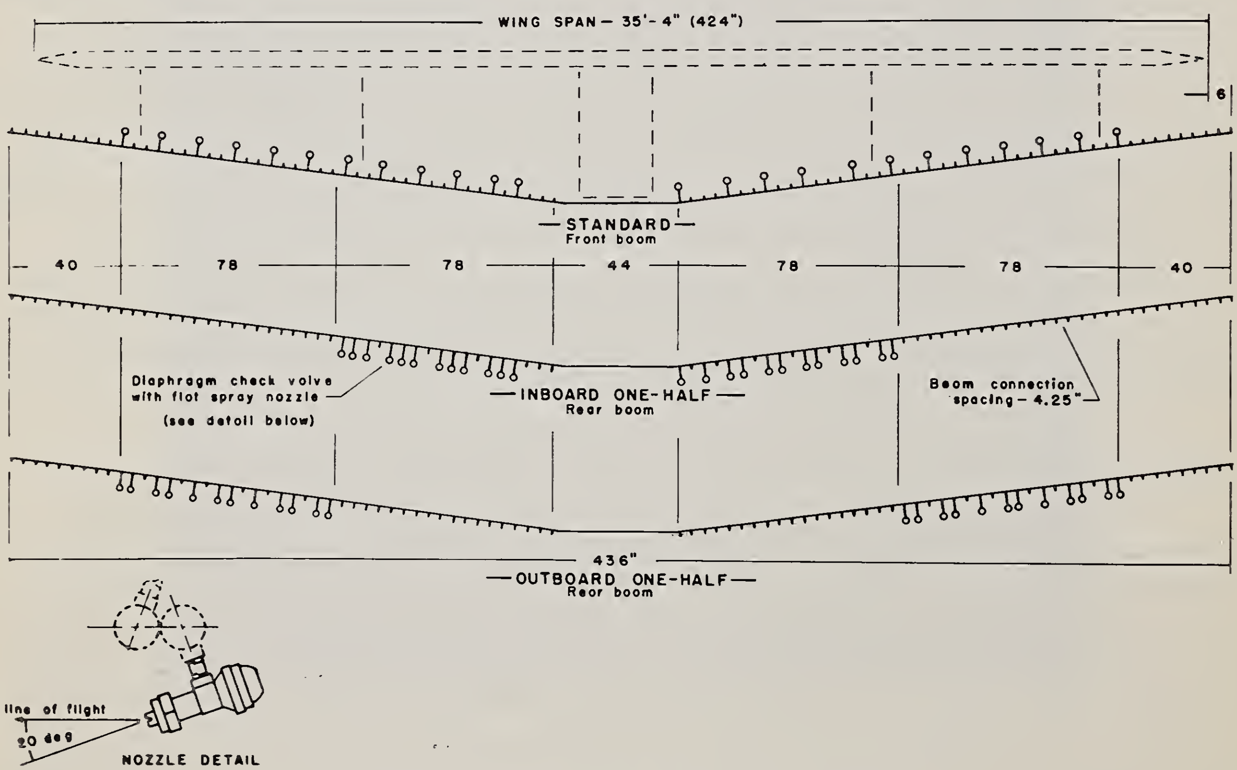

Figure 7.--Nozzle arrangements used on PA-18A.

Table 1.--Weather observations during 4 test flights and percentage spray recovery from front and rear booms

Flight number	Weather observations					Recovery	
	Wind		Temperature			Front boom	Rear boom
	at 5 feet	at 50 feet	at 5 feet	at 50 feet	Gradient[1]		
	m.p.h.	m.p.h.	°F.	°F.	°F.	Percent	Percent
1	2.0	6.0	74.1	78.3	+ 4.2	69.3	70.7
2	1.4	4.0	67.2	69.0	+ 1.8	83.6	77.2
3	.5	.5	69.7	72.9	+ 3.2	72.4	72.3
4	1.6	4.2	68.0	72.0	+ 4.0	69.6	70.6
Average.	1.4	3.7	69.8	73.1	+ 3.3	73.7	72.7

[1] + denotes inversion.

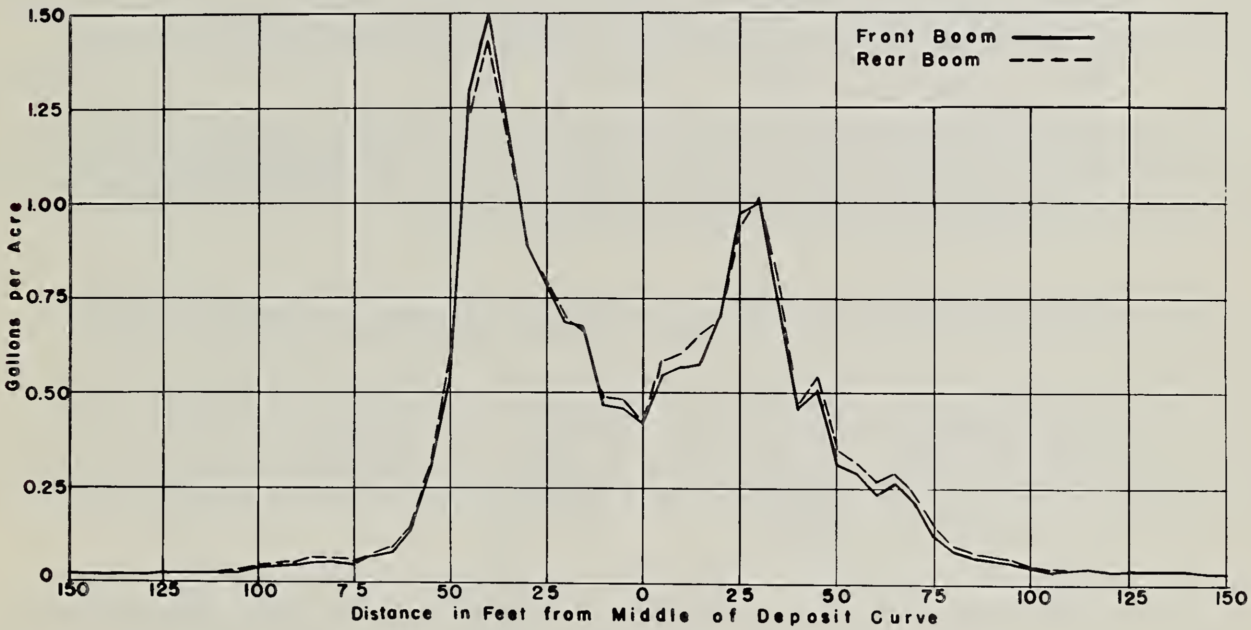

Figure 8.--Spray-distribution patterns from front and rear booms - average of three flights.

An examination of the deposit graphs (not shown) for the individual flights in this series indicated that the higher peaks at the left were in part due to light crosswinds from the left during two of the flights. In general, when there is a crosswind effect, the peak of spray deposit on the upwind side is higher than that on the downwind side.

The swath was slightly wider from the rear boom than from the front one at the 0.2 to 0.5 g.p.a. deposit levels (table 2). The 4.4 percent higher flow rate from the rear boom may have caused some of this increase.

Table 2.--Average swath width at different deposit levels for front and rear booms

Deposit level, g.p.a.	Swath width, in feet[1]	
	Front boom	Rear boom
0.1	167	164
.2	135	137
.3	122	127
.4	92	99
.5	73	78

[1] Distance over which deposit level was not less than that given in the left column.

For the four flights there was a total of 251 samples of spray deposit from each boom. The average deposit per sample was 0.303 g.p.a. from the front boom and 0.313, or about 3.3 percent more, from the rear boom. No doubt this was the result of the flow rate from the rear boom being 4.4 percent higher and spray recovery being 1 percent lower than that from the front boom.

An analysis of the difference between the deposit from front and rear booms at each of the 251 sampling stations showed a mean difference of 0.0278 g.p.a. The standard error of this mean difference was $\pm$0.0046 g.p.a. at the 95-percent probability level.

Spray Deposits From the Standard Boom and Inboard Half of Boom

The nozzle arrangements used are shown in figure 7. Four flights were made in this series. In three of the flights the spray tended to drift to the right and in the other to the left. Weather observations (table 3) show that wind speed was not greater than 2.8 m.p.h. for any of the tests. There was an inversion of 1 to 5 degrees.

The average flow rate from the standard boom was 20.5 g.p.m. From the inboard half it was 21.4 g.p.m., or 4.4 percent more. Average percentage recovery of the spray was 80.4 from the standard boom. From the inboard half it was 81.2, or 0.8 percent more.

Deposit patterns produced by the two nozzle arrangements are shown in figure 9. The curves show the average for the three flights (2, 3, and 4) in this series that were most directly upwind. From these curves and the other data shown, it is apparent that the inboard arrangement produced a narrower swath than the standard arrangement and was less satisfactory. There was very little difference in the heights of the deposit peaks from the two nozzle arrangements. Those from the inboard arrangement, however, were much closer to the center of the swath than those from the standard arrangement. However, the deposit rate at the low point in the center of the swath was significantly less for the standard arrangement. Both levels, however, were above that generally required for control of common forest insect defoliators.

The swath widths produced by the two booms are shown in table 4. The width of swath at deposit levels of 0.1 to 0.5 g.p.a. was greater from the standard boom. Differences between deposit levels were significant except at the 0.1 g.p.a. level.

Table 3.--Weather observations during 4 test flights and percentage spray recovery for the standard boom and inboard half of boom

Flight number	Weather observations					Recovery	
	Wind		Temperature			Standard	Inboard half
	at 5 feet	at 50 feet	at 5 feet	at 50 feet	Gradient[1]		
	m.p.h.	m.p.h.	°F.	°F.	°F.	Percent	Percent
1	0.5	2.8	59.0	63.0	+ 4.0	68.5	74.6
2	1.0	1.6	62.8	63.8	+ 1.0	77.7	77.0
3	1.2	2.6	67.0	68.5	+ 1.5	80.1	78.1
4	.5	.5	60.5	65.5	+ 5.0	95.4	94.9
Average	.8	1.9	62.3	65.2	+ 2.9	80.4	81.2

[1] + denotes inversion.

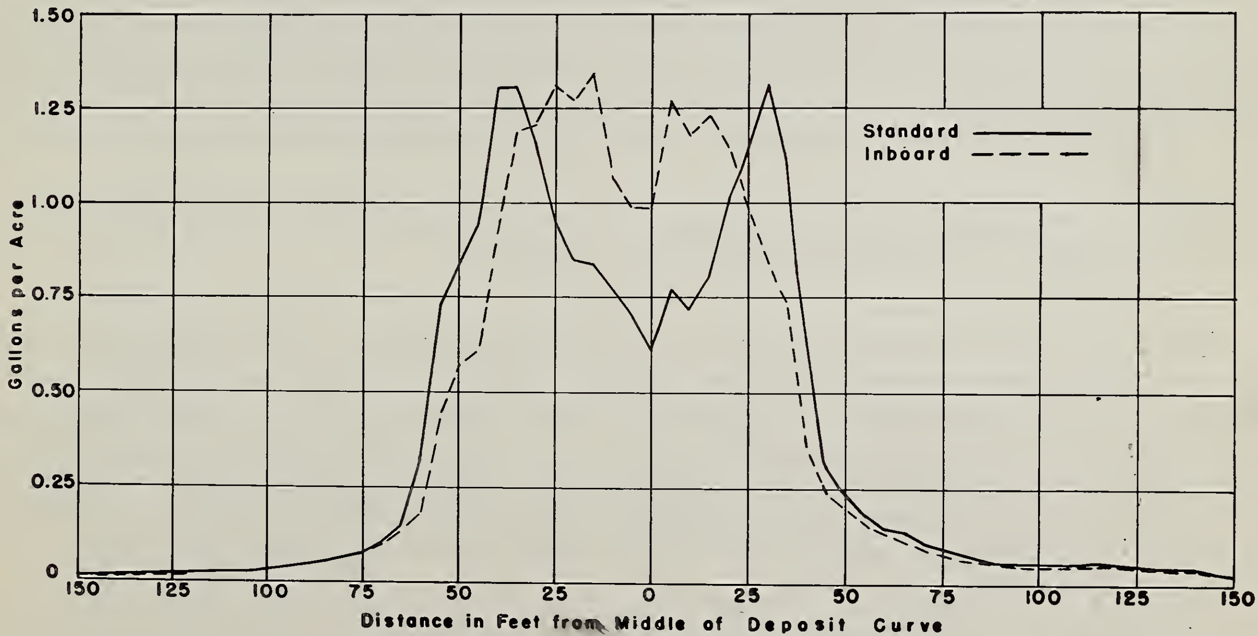

Figure 9.--Spray-distribution patterns from standard and inboard nozzle arrangements - average of three flights.

Table 4.--Average swath width at different deposit levels for standard boom and inboard half of boom

Deposit level, g.p.a.	Swath width, in feet[1]		Difference
	Standard	Inboard half	
0.1	142	135	[2] 7
.2	119	113	[3] 6
.3	105	98	[3] 7
.4	97	91	[3] 6
.5	93	87	[3] 6

[1] Distance over which deposit level was not less than that given in the left column.
[2] Not significant.
[3] Significant at 95-percent probability level.

Spray Deposits From the Standard Boom and Outboard Half of Boom

The nozzle arrangements used for this series of tests are shown in figures 4 and 7. Eight flights were made in this series. Five of these were generally upwind, but during the other three there was some crosswind from the right. Weather observations (table 5) show that wind speed at 5 feet ranged from calm to 6 m.p.h. and averaged 1.8. At 50 feet the range was from calm to 8.6 m.p.h. and the average was 4.3. The 107 and 117 percent recovery for flight 3 is unusual. The spray deposit curves for this flight had excessively high deposit peaks--over 2.5 g.p.a. from the left outboard arrangement. This excess deposit was probably caused by a part of the spray cloud that was released upwind of the sampling line being carried back onto the deposit cards by freakish air currents. The wind speed during flight 4 was considerably greater than is desirable; as a result percentage recovery was well below normal for the flight.

Flow rate was 20 g.p.m. from the standard boom and 19.9 from the outboard half. The spray recovery averaged 76.5 percent from both booms (table 5).

The spray-deposit curves in figure 10 show the swath patterns produced by the two booms. The curves show the average for the three flights (1, 6, and 7) of the series that were most directly upwind. The outboard arrangement of nozzles produced very high deposit peaks about 75 feet apart and a very low deposit (about 0.1 g.p.a.) in the middle. There was practically no difference in lateral spread of the spray between the two nozzle arrangements at the 0.25 to 0.5 g.p.a. deposit levels. The outboard arrangement of nozzles is undesirable because of the low deposit in the middle of the swath and the excessively high deposit peaks on each side.

Comparison of swath width produced by the two booms is shown in table 6. Deposit at the 0.1 g.p.a. level was about the same from both booms. At levels from 0.2 to 0.5 g.p.a. the standard boom resulted in a wider swath than the outboard half, but this difference was not significant.

Table 5.--Weather observations during 8 test flights and percentage spray recovery from standard boom and outboard half of boom

Flight number	Weather observations					Recovery	
	Wind		Temperature			Standard	Outboard half
	at 5 feet	at 50 feet	at 5 feet	at 50 feet	Gradient[1]		
	m.p.h.	m.p.h.	°F.	°F.	°F.	Percent	Percent
1.	2.8	5.0	69.5	72.0	+2.5	69.3	64.7
2.	2.8	5.2	66.0	68.0	+2.0	70.3	66.5
3.	1.0	---	62.0	64.0	+2.0	107.0	117.2
4.	6.0	8.6	70.2	69.3	-.9	50.5	59.7
5.	1.0	---	53.3	54.7	+1.4	79.8	77.4
6.	0	0	55.5	55.5	0	88.3	87.4
7.	.5	4.6	59.9	61.8	+1.9	80.3	70.7
8.	0	2.6	---	---	---	66.8	68.3
Average	1.8	4.3	62.3	63.6	+1.3	76.5	76.5

[1] + denotes inversion; - denotes lapse.

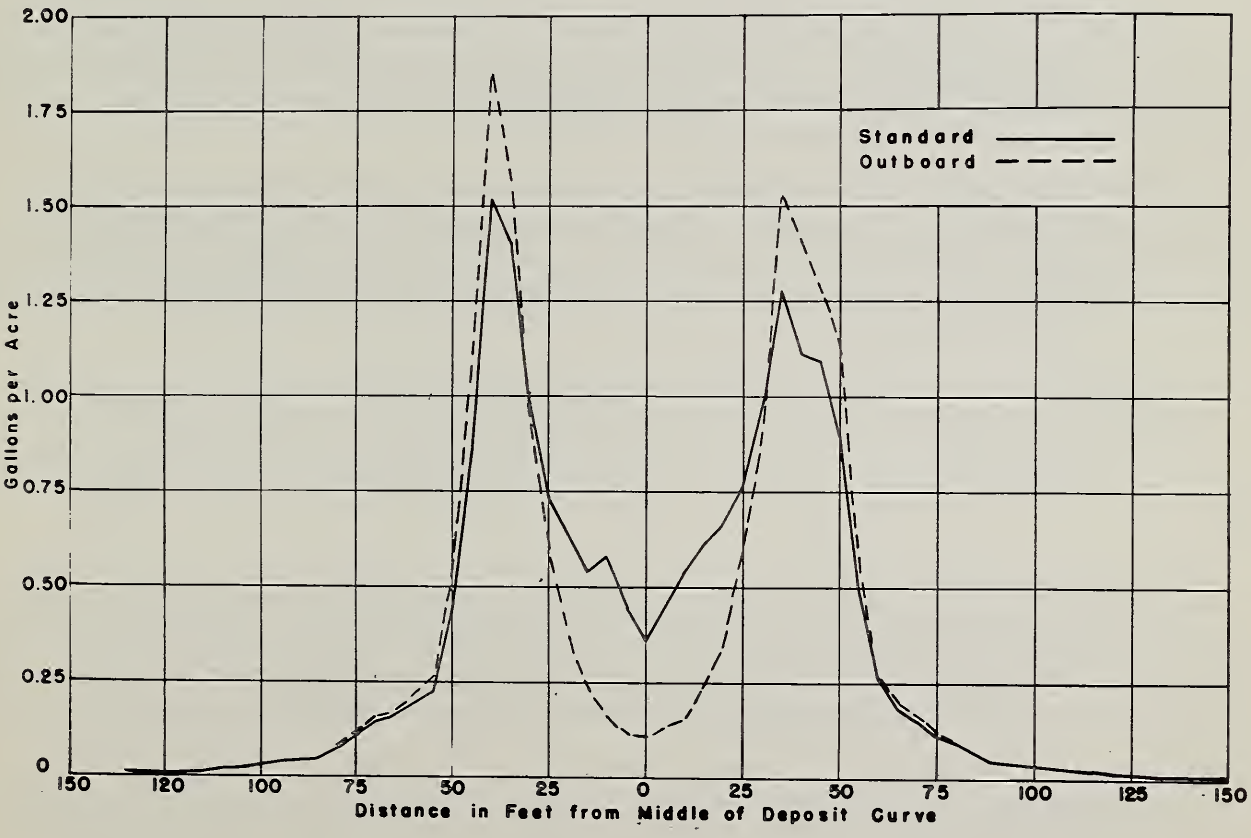

Figure 10.--Spray-distribution patterns from standard and outboard nozzle arrangements - average of three flights.

Table 6.--Average swath width at different deposit levels for standard boom and outboard half of boom

Deposit level, g.p.a.	Swath width, in feet[1]		
	Standard	Outboard half	Difference[2]
0.1	156	157	1
.2	122	118	4
.3	110	96	14
.4	95	83	12
.5	80	70	10

[1] Distance over which deposit level was not less than that given in the left column.
[2] Not significant.

Spray Deposits From Three Nozzle Arrangements

A comparison of the spray deposits from the three different nozzle arrangements used in this study is shown in figure 11. The deposit curve for the inboard half is from figure 9, the curve for the outboard half is from figure 10, and the curve for the standard boom is the average of the standard boom curves from figures 9 and 10.

The inboard arrangement resulted in the narrowest swath even though distribution was fairly uniform over about 65 feet of swath at the 1 g.p.a. level. The outboard arrangement resulted in excessively high deposit peaks with no increase in lateral distribution of spray. Deposit level at the middle of the swath was very low.

Additional tests may show that it is possible to further improve uniformity of distribution by other nozzle arrangements or by varying the degree of atomization. The effect of reduced flow rate on spray distribution was not studied with the PA-18A as it was with the Stearman.[8]

There was a minimum lateral displacement of the spray under the narrowly restricted weather conditions (upwind, low wind velocity, and inversion) specified for the tests. However, with considerable crosswind (velocity up to 6 m.p.h.) as may occur on most control operations, the peaks of spray deposit are leveled off and uniformity of distribution is improved.

[8] See footnote 3, p. 3.

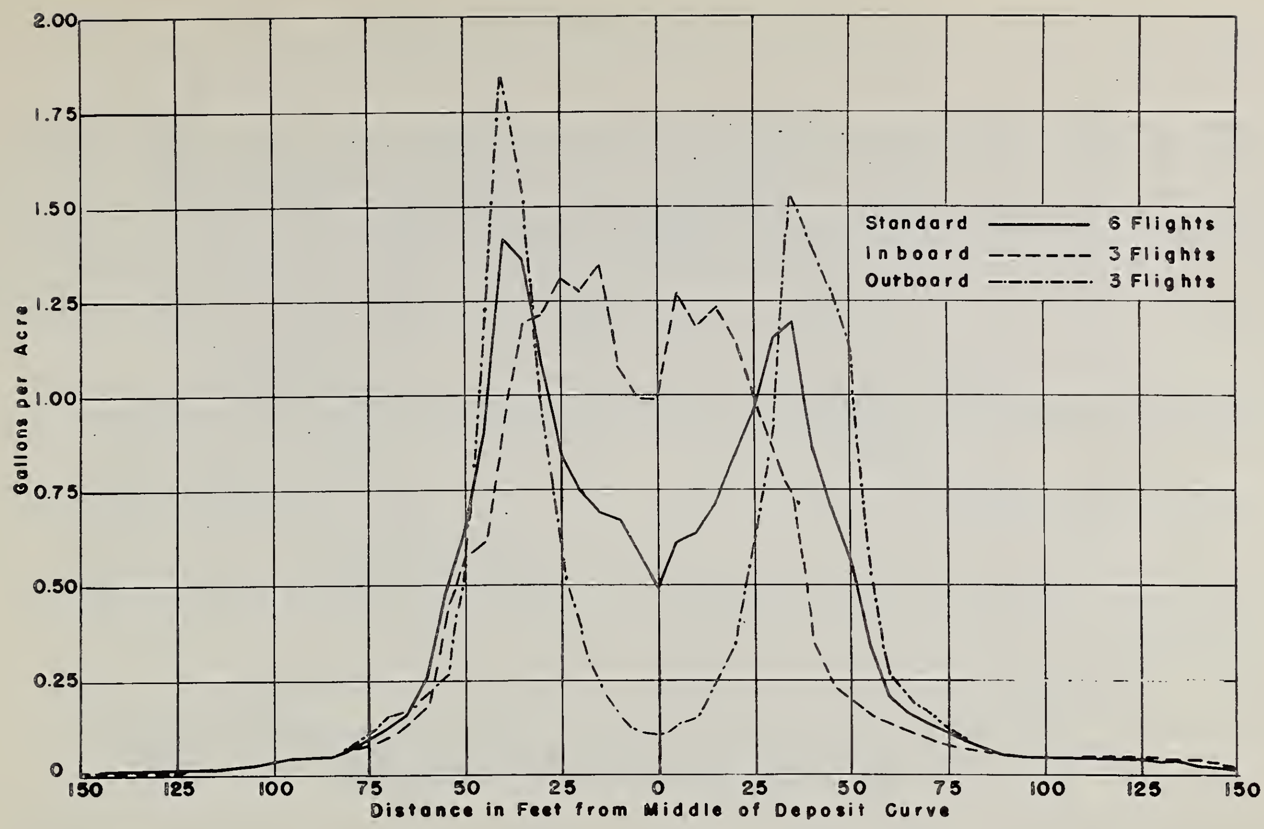

Figure 11.--Spray-distribution patterns from standard, inboard, and outboard nozzle arrangements.

Some Comparisons of a Piper PA-18A with a Stearman

Average spray-deposit patterns developed from 5 selected flights made with the PA-18A and from 17 flights with a 220 h.p. Stearman are shown in figure 12. These flights were made under the operating conditions described under "Equipment and Procedure." Although different types of nozzles were used on the two planes, the atomization was approximately the same. The standard, or full-boom, arrangement of nozzles was used on both planes.

The data for the two graphs were from flights selected to conform to the following criteria:

1. Not less than 50 feet from trough to short side of swath with a deposit of 0.05 g.p.a.
2. Not more than 0.6 g.p.a. difference between deposit peaks.
3. Between 60- to 90-percent spray recovery.
4. A deposit of not more than 0.05 g.p.a. at either end of the line.

Similar bimodal spray-deposit patterns were produced by the two planes. Deposit peaks were about 80 feet apart with the Stearman and about 65 feet with the PA-18A. At the deposit levels of 0.1 to 0.3 g.p.a. the width of swath was greater with the Stearman (table 7). These results indicate that the combined effect of wingtip vortex and location of boom produced greater lateral movement of spray from the Stearman than it did from the PA-18A.

A major difference in results obtained by the two planes was the effect on spray distribution of nozzles located in the inboard half of the boom. With the Stearman, there was no difference in distribution produced by nozzles located along a full-span boom or only along the inboard half when a spray of medium atomization was used. In contrast, with the Piper PA-18A when the nozzles were located along the inboard half of the boom a narrower swath was produced than that produced when they were located along a standard-length boom.

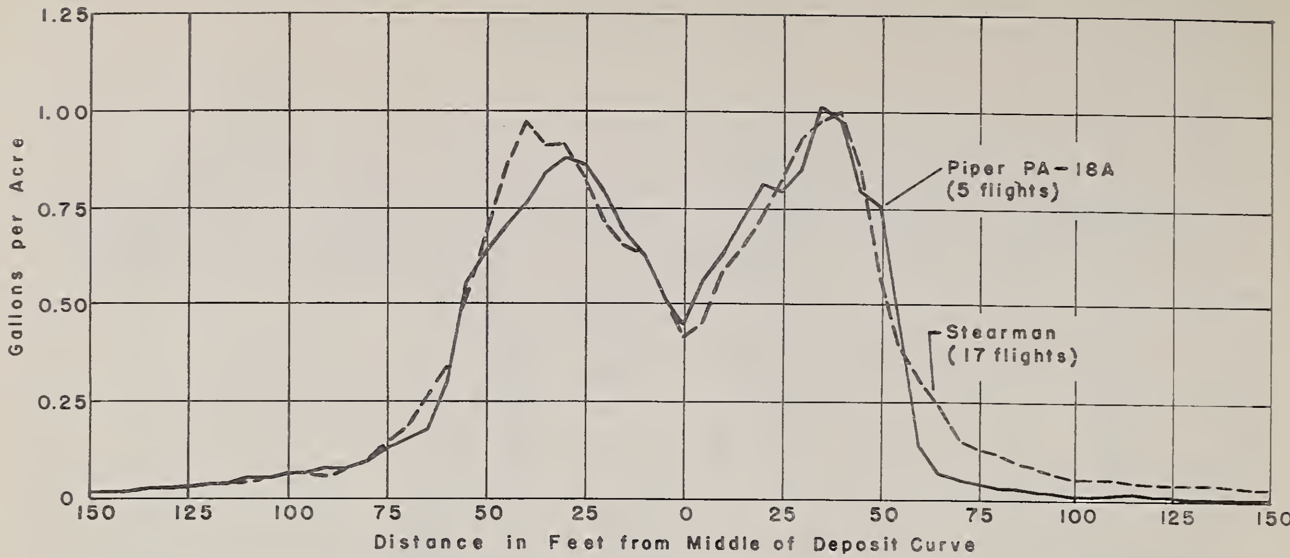

Figure 12.--Average spray-distribution patterns from Piper PA-18A and 220 h.p. Stearman airplanes.

Table 7.--Average swath width at different deposit levels from 17 flights with a Stearman and 5 with a Piper plane

Deposit level, g.p.a.	Swath width, in feet[1]	
	Stearman (220 h.p.)	Piper PA-18A (135 h.p.)
0.1	166	142
.2	137	123
.3	124	117
.4	113	113
.5	97	105

[1] Distance over which deposit level was not less than that given in the left column.

Some of the reasons for the difference between the two planes were:
1. The greater horsepower and higher gross weight of the Stearman.
2. The Stearman was a biplane, and the Piper PA-18A a highwing monoplane.
3. The location of boom relative to wing.

An average of 75 percent of the spray released from the 5 flights of the Piper PA-18A was recovered on the ground as compared with 76 percent from the 17 flights of the Stearman--no practical difference.

SUMMARY AND CONCLUSIONS

These studies with a Piper PA-18A show that the location of the nozzles along the spray boom has an effect on the spray-deposit pattern when flights are made at a height of 50 feet. They show that when nozzles that deliver a spray of medium atomization are used a bimodal curve of spray deposit is produced during upwind flights. Heavy peaks of deposit are produced outboard from the wingtips 30 to 35 feet from each side of the flight line. A low level, or trough, of deposit is produced approximately under the center of the plane.

Several nozzle arrangements were studied with the following results:

1. Nozzles on both the front and rear booms of a dual sprayer.--Distribution of spray released from nozzles on the front boom was essentially the same as that released from nozzles on the rear boom.
2. Nozzles on inboard half of boom.--The inboard arrangement resulted in a narrower swath than did the standard boom.
3. Nozzles on outboard half of boom.--The outboard arrangement resulted in excessively high deposit peaks and an excessively low deposit level in the middle of the swath. It resulted in a swath width that was not significantly greater than from the standard boom. It is the conclusion that the outboard arrangement of nozzles is undesirable.
4. Standard arrangement of nozzles.--Spray distribution from the standard arrangement of nozzles was more satisfactory than that from the other two arrangements.

Similar bimodal spray-deposit patterns were produced by the Piper PA-18A and the 220-h.p. Stearman. The two peaks of deposit were about 80 feet apart with the Stearman and 65 feet with the PA-18A. At the deposit levels of 0.1 to 0.3 g.p.a. the width of swath was somewhat greater with the Stearman. There was no practical difference between the two planes in percentage of spray recovered on the ground.

RECOMMENDATIONS

The following recommendations apply for a Piper PA-18A or similar airplane when spraying forests (a) with application rates up to 1 g.p.a. of a conventional oil-base insecticide, (b) with a medium spray atomization of approximately 150 microns mass medium diameter, and (c) while flying at a height greater than 50 feet above the trees:

1. Adjust the flow rate to cover an effective swath of not more than 100 feet when swath spacing can be rather accurately controlled, as by use of flagmen. Otherwise, adjust it to cover an effective swath of 75 feet so that the overlap will compensate for variations in swath interval.
2. Space the nozzles evenly along the standard-length boom.